

CLAIMS

What is claimed is:

- 1 1. Apparatus for carrying out Czochralski crystal growth
2 comprising:
 - 3 (a) a crucible having a bottom, a sidewall and an open top, with
4 an axial height from the open top to the bottom;
 - 5 (b) an upper heater around the crucible to apply heat to an upper
6 portion of the crucible;
 - 7 (c) a lower heater around the crucible below the upper heater to
8 apply heat to a lower portion of the crucible, the lower heater operable
9 independently of the upper heater so that the heat applied by the upper heater and
10 the lower heater to the crucible can be selected;
 - 11 (d) heat insulation between the upper and lower heaters; and
 - 12 (e) an axially advanceable crucible support under the crucible on
13 which the crucible is supported.
- 1 2. The apparatus of Claim 1 including means for drawing a
2 solidified crystal from liquid melt in the crucible through the open top of the
3 crucible.
- 1 3. The apparatus of Claim 1 including heat insulation around and
2 spaced outwardly from the upper and lower heaters.
- 1 4. The apparatus of Claim 1 further including a solid feed
2 material occupying a lower portion of the crucible, a liquid melt of the feed material
3 over the solid material which occupies a region of the crucible above the solid feed
4 material, a liquid encapsulant material over the liquid melt occupying a region of
5 the crucible above the liquid melt, and means for drawing a solidified crystal from
6 the liquid melt through the liquid encapsulant.

1 5. The apparatus of Claim 4 wherein the top of the solid feed
2 material in the crucible is at a height adjacent to the insulation between the upper
3 and lower heaters.

1 6. The apparatus of Claim 4 wherein the means for drawing the
2 crystal also rotates the crystal being drawn from the melt.

1 7. The apparatus of Claim 4 wherein the solid feed material is
2 In-doped GaAs and the liquid melt is In-doped GaAs.

1 8. The apparatus of Claim 4 wherein the solid feed material is an
2 alloy of GaAs and InAs.

1 9. The apparatus of Claim 1 further including a temperature
2 sensor positioned to sense the temperature of the lower heater in the region of the
3 solid feed material and a temperature sensor positioned to sense the temperature of
4 the heater in the region of the liquid feed melt material.

1 10. The apparatus of Claim 1 wherein the aspect ratio of the axial
2 length of the crucible to the diameter of the crucible is at least 2 to 1.

1 11. The apparatus of Claim 1 wherein the crucible comprises an
2 outer crucible holder and an inner crucible held within the crucible holder.

1 12. The apparatus of Claim 11 wherein the inner crucible is
2 formed of pyrolytic BN.

1 13. A method of carrying out Czochralski crystal growth
2 comprising:

3 (a) providing a crucible with a solid feed material therein having
4 a desired concentration of constituents for the crystal to be grown;

5 (b) heating an upper portion of the crucible with an upper heater
6 to a temperature sufficient to melt the feed material in an upper portion of the
7 crucible and separately heating a lower portion of the crucible with a lower heater

8 to another temperature which is below the melt temperature of the feed material so
9 that the feed material in the lower portion of the crucible remains solid;

10 (c) growing a crystal from the melt and drawing the growing
11 crystal out of the melt;

12 (d) advancing the crucible with respect to the heaters as the
13 crystal is drawn from the melt to heat additional portions of solid feed material with
14 the upper heater to melt the additional solid material to replace the crystal drawn
15 from the melt.

1 14. The method of Claim 13 further including rotating the crystal
2 as it is drawn from the melt.

1 15. The method of Claim 13 further including covering the melt
2 with a liquid encapsulant material while growing the crystal from the melt and
3 drawing the growing crystal out of the melt.

4 16. The method of Claim 15 wherein the feed material is In-doped
5 GaAs.

1 17. The method of Claim 16 wherein the liquid encapsulant
2 material is B₂O₃.

1 18. The method of Claim 15 wherein the feed material is an alloy
2 of InAs and GaAs.

1 19. The method of Claim 18 wherein the liquid encapsulant is
2 B₂O₃.

1 20. The method of Claim 13 wherein the feed material is SiGe.

1 21. The method of Claim 13 wherein the step of providing a
2 crucible with a solid feed material therein includes filling the crucible with a
3 mixture of particulate feed material having the desired concentration of constituents,
4 heating the particulate material to melt it in the crucible and thoroughly mixing the
5 melted material, then freezing the melted material to form a solid feed material in

6 the crucible, and then heating an upper portion of the feed material in the crucible
7 with the upper heater to a temperature above the melting temperature of the
8 material.

1 22. The method of Claim 13 wherein the step of growing a crystal
2 from the melt includes contacting the melt with a seed crystal at an end of a crystal
3 pulling rod to grow crystal from the melt onto the seed and then drawing the rod
4 upwardly to draw the growing crystal from the melt.

1 23. The method of Claim 22 further including reducing the heat
2 applied by the upper heater after the seed crystal contacts the melt to lower the
3 temperature of the melt to allow crystal to grow on the seed.

1 24. The method of Claim 23 further including raising the heat
2 applied by the lower heater to the solid feed material after the seed crystal contacts
3 the melt to raise the temperature of the solid feed material and melt an additional
4 portion of the solid feed material to reduce the change in the depth of the melt as
5 the crystal is grown on the seed.

1 25. The method of Claim 13 wherein the crucible is advanced
2 with respect to the heaters at a speed $V_c = V_s (d_s/d_c)^2$, where V_s is the speed at which
3 the crystal is drawn from the melt, d_s is the diameter of the crystal as drawn from
4 the melt, and d_c is the inner diameter of the crucible.

1 26. The method of Claim 13 wherein before drawing the crystal
2 from the melt, the melt is leveled by the addition of a desired dopant to adjust the
3 melt concentration to a level C_o/k , where C_o is the desired dopant concentration in
4 the crystal and k is an experimentally determined constant.

1 27. The method of Claim 13 further including maintaining the
2 crucible in an enclosure containing an inert gas atmosphere.

1 28. The method of Claim 13 wherein the upper and lower heaters
2 maintain the uppermost portion of the melt at a higher temperature than the

3 lowermost portion of the melt to maintain a temperature gradient in the melt to
4 enhance convection mixing of the melt.

1 29. A method of carrying out liquid encapsulated Czochralski
2 crystal growth comprising:

3 (a) providing a crucible with a solid feed material therein having
4 a desired concentration of constituents for the crystal to be grown;

5 (b) heating an upper portion of the crucible with an upper heater
6 to a temperature sufficient to melt the feed material in an upper portion of the
7 crucible and separately heating a lower portion of the crucible with a lower heater
8 to another temperature which is below the melt temperature of the feed material so
9 that the feed material in the lower portion of the crucible remains solid;

10 (c) growing a crystal from the melt and drawing the growing
11 crystal out of the melt while covering the melt with a liquid encapsulant material;

12 (d) advancing the crucible with respect to the heaters as the
13 crystal is drawn from the melt to heat additional portions of solid feed material with
14 the upper heater to melt the additional solid material to replace the crystal drawn
15 from the melt.

1 30. The method of Claim 29 further including rotating the crystal
2 as it is drawn from the melt.

1 31. The method of Claim 29 wherein the feed material is In-doped
2 GaAs.

1 32. The method of Claim 31 wherein the liquid encapsulant
2 material is B₂O₃.

1 33. The method of Claim 29 wherein the feed material is an alloy
2 of InAs and GaAs.

1 34. The method of Claim 33 wherein the liquid encapsulant is
2 B₂O₃.

1 35. The method of Claim 29 wherein the step of growing a crystal
2 from the melt includes contacting the melt with a seed crystal at an end of a crystal
3 pulling rod to grow crystal from the melt onto the seed and then drawing the rod
4 upwardly to draw the growing crystal from the melt and through the liquid
5 encapsulant.

1 36. The method of Claim 29 wherein before drawing the crystal
2 from the melt, the melt is leveled by the addition of a desired dopant to adjust the
3 melt concentration to a level C_0/k , where C_0 is the desired dopant concentration in
4 the crystal and k is an experimentally determined constant.

1 37. The method of Claim 29 wherein the step of providing a
2 crucible with a solid feed material therein includes filling the crucible with a
3 mixture of particulate feed material having the desired concentration of constituents
4 and the encapsulant, heating the particulate material to melt it in the crucible and
5 thoroughly mixing the melted material, then freezing the melted material to form a
6 solid feed material in the crucible, and then heating an upper portion of the feed
7 material in the crucible with the upper heater to a temperature above the melting
8 temperature of the material.